EXPECTED PROPERTIES OF PRIMEVAL GALAXIES AND CONFRONTATION WITH EXISTING OBSERVATIONS

Daniel Schaerer
Geneva Observatory, 51, Ch. des Maillettes, CH-1290 Sauverny, Switzerland
daniel.schaerer@obs.unige.ch

1. Properties of low metallicity and PopIII starbursts – predictions and confrontation with existing observations

Based on existing or new stellar tracks and appropriate non-LTE model atmospheres we have recently undertaken a systematic study of the expected restframe EUV, UV to optical properties of starbursts of zero and higher metallicity (Schaerer 2002, 2003, hereafter S02, S03). These studies provide predicted SEDs including stellar and nebular emission (continuum and lines), detailed ionizing properties, calibrations for star formation indicators (S03), and also predicted metal production rates for various elements (S02). These should be useful for a variety of studies concerning high redshift galaxies, cosmological reoinisation studies and others.

Among the main observational characteristics found for PopIII and metal-poor starbursts are:

1) Continuum emission is expected to be dominated by nebular (bound-free, free-free and two photon) emission even in the rest-frame UV domain (S02). This leads to a flatter intrinsic SED compared to normal galaxies.

2) The maximum Ly-α emission (i.e. neglecting possible radiation transfer effects trought the galaxian ISM and IGM and dust) of integrated stellar populations increases quite strongly with decreasing metallicity. This is illustrated in Fig. 1a considering also various cases of the IMF at low metallicity.

3) Strong He II recombination lines (He II λ1640, He II λ4686,...) are a quite unique signature due to hot massive main sequence stars of PopIII/very low metallicity (cf. Tumlinson & Shull 2000). Significant He II emission is, however, only expected at metallicities below $\lesssim 10^{-5}$ solar (S03). This is e.g. illustrated by plotting the ratio of He$^+$ to H ionizing photons, $Q(\mathrm{He}^+)/Q(\mathrm{H})$, computed for a SF population at equilibrium, i.e. for constant SF (Fig. 1b).

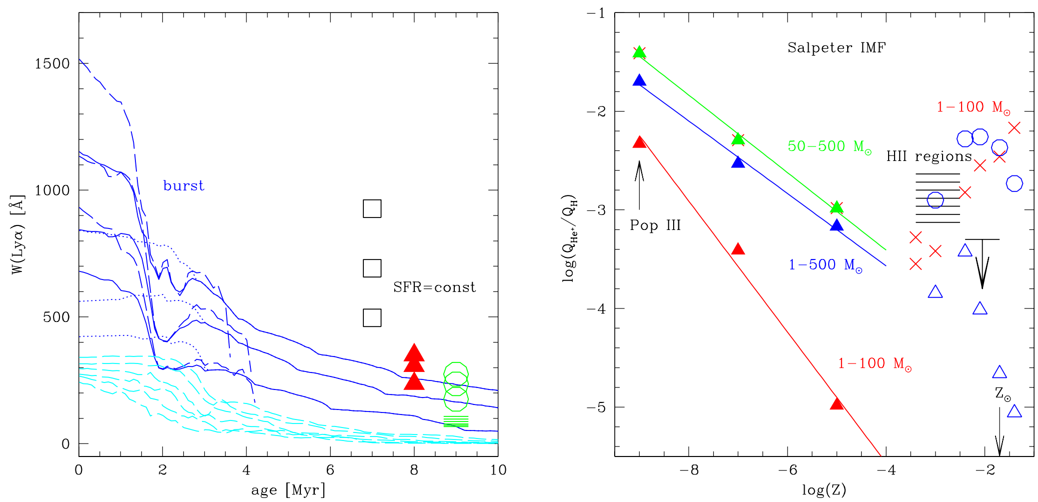

Figure 1. **a–left:** Predicted Ly-α equivalent widths for bursts of different metallicities and IMFs. **b–right:** Predicted hardness $Q(\mathrm{He}^+)/Q(\mathrm{H})$ as a function of metallicity for starbursts between PopIII and normal metallicities. Figures taken from Schaerer (2003) – see there for a complete explanation of the figures

These findings are also confirmed by the study of Panagia, Stiavelli, and collaborators (see these proceedings).

In short, the following three characteristics can be identified as fairly clear signatures of very metal-poor or PopIII starbursts ("primeval galaxies"): Strong Ly-α emission, narrow nebular He II emission, and very weak or absent metal lines. We now discuss more precisely these "criteria" and confront them with existing observations.

1.1 Strong Ly-α emission

If Ly-α equivalent widths $\gtrsim$ 500 A are measured, this would, according to Fig. 1a, require stellar populations with metallicities $Z \lesssim 10^{-5}$ (i.e. [Z/H] $\lesssim -3.3$ in solar units) and/or an extreme IMF. Such large $W(\mathrm{Ly}-\alpha)$ cannot be explained by stellar photoionisation in galaxies with a Salpeter like IMF and higher metallicities. Alternative explanations include AGNs.

In fact a good fraction of the Ly-α emitters found by the LALA survey seems to show such large equivalent widths (Malhotra & Rhoads 2002). However, it must be remembered that the equivalent widths are determined from narrowband (NB) and R-band imaging, which could lead to important uncertaintied, as e.g. noted by comparing similar data from NB imaging and spectroscopy of SUBARU data of Ouchi et al. (2003 and private comm.). Spectro-

scopic follow-up of 5 LALA sources seem, however, to confirm their previous equivalent widths measurements from imaging (Rhoads et al. 2003). In principle it is thus possible that (some of) the strong Ly-α emitters of the LALA are such primeval galaxies. Whether such large numbers of objects at relatively low redshifts (e.g. at $z = 4.5$ Malhotra & Rhoads 2002) would truly be expected seems surprising (cf. Scannapieco et al. 2003). No doubt detailed follow-up work on these objects will be of great interest.

1.2 Nebular He II emission

As mentioned above the detection of nebular He II emission lines above a certain level (e.g. W(He II λ1640) $\gtrsim$ 10 A or He II λ1640/H$\beta \gtrsim 0.05$, see S03) would be a very strong case for a very metal-poor if not metal-free stellar population if shown to originate from stellar photoionisation (as opposed e.g. to AGN activity).

Tumlinson et al. (2001) have speculated whether such objects could already have been found “accidentaly” at $z \lesssim 5$, confused with Ly-α emitters whose redshift is identified by a single line measurement. Their simulations (in rough agreement with our more detailed results) show that this should then correspond to PopIII objects with high star formation rates comparable to those determined for Lyman break galaxies. This may again be questionable on grounds of the fairly small probability of existence of PopIII galaxies at such “low” redshifts. However, the current observations do not allow to prove or disprove their speculation.

During this conference my attention was brought to the discovery of an unusual $z = 3.357$ lensed galaxy showing narrow He II emission lines (among others) indicative of a fairly high excitation (see Fosbury et al. 2003). These authors speculate that this might be ionised by a very hard stellar spectrum possibly due to an extremely metal-poor stellar cluster. However, this seems quite unlikely for the following reasons. First numerous metal lines are seen (including in the UV spectrum) indicating an ISM metallicity of $\sim$ 1/20 solar, and [O III] λ5007/H$\beta \sim$ 7.5 is typical of metal-poor H II galaxies. Furthermore, no case is known where the stellar metallicity is lower than the nebular one. This would require quite exotic formation and mixing scenarios, in contradiction with our current knowledge of SF galaxies in the nearby Universe. Finally, an alternative explanation (obscured AGN) exists capable of reproducing the observed emission line properties (Binette et al. 2003). Although this peculiar object is certainly of great interest it appears unlikely that it is related to an extremely metal-poor or even PopIII starburst.

1.3 Weak/absent metal lines

Establishing the weakness or absence of metal lines will ultimately be important to prove the extremely low or zero metallicity case. From simple photoionisation modeling Panagia (these proceedings and 2003) propose e.g. that [O III] λ5007/Hβ $\lesssim$ 0.1 (0.01) should indicate a metallicity $\lesssim 10^{-3}$ (10^{-4}) solar, approximately corresponding to the expected metallicity of second generation stars (see also Scannapieco et al.). Above redshift $z \gtrsim 4$, a measurement of [O III] λ5007 will require sensitive space instruments like those planned for the JWST. Up to redshift $z \lesssim 9$ such observations should be feasible with the NIRSpec multi-object spectrograph (e.g. Panagia 2003). Beyond that, explorations will be very difficult and time consuming as single object spectroscopy (MIRI) will only be available at the corresponding wavelengths ($\lambda > 5 \mu m$).

2. Into the future...

From the above it is evident that no genuine PopIII object or extremely metal-poor galaxy ($Z/Z_{\odot} \lesssim 10^{-3...-4}$) has been found so far. Currently the best candidates are the high Ly-α equivalent widths objects from the LALA survey whose properties remain puzzling. However, given their fairly large number and relatively low redshift ($z \sim 4.5$) it would at first be surprising if many would truly correspond to this category.

Other indepedent options to search for such "primeval" galaxies and higher z objects should be explored. The feasibility of such studies has been addressed e.g. in Schaerer & Pelló (2001) and Pelló & Schaerer (2002). Possible avenues include among others the use of particular broad-band selection criteria and ultra-deep near-IR imaging to find new candidates. Preliminary results from such studies are discussed by Richard et al. (2003) in these proceedings. There is little doubt that the great progress made over recent years on the exploration of the high redshift Universe will continue and possibly even truly "primeval" galaxies or PopIII objects will be found in this decade and before the JWST will be available. We look forward to exciting times!

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